Introduction to FACTS Controllers: A Technological Literature Survey

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Abstract

This paper presents a review on applications of Flexible AC Transmission Systems (FACTS) controllers such as Thyristor Controlled Reactor (TCR), Thyristor Controlled Switched Reactor (TCSR), Static VAR Compensator (SVC) or Fixed Capacitor- Thyristor Controlled Reactor (FC-TCR), Thyristor Controlled Series Capacitor (TCSC), Thyristor Controlled Switched Series Reactor (TSSR), Thyristor Controlled Brakening Reactor (TCBR), Thyristor Controlled Voltage Reactor (TCVR), Thyristor Controlled Voltage Limiter (TCVL Thyristor Controlled Switched Series (TSSC), Thyristor Controlled Phase Angle Regulator (TC-PAR) or Thyristor Controlled Phase Shift Transformer (TC-PST), Static Synchronous Series Compensator (SSSC), Static Synchronous Compensator (STATCOM), Distributed Static Synchronous Compensator (D-STATCOM), Generalized Unified Power Flow Controller (GUPFC), Unified Power Flow Controller (UPFC), Inter-link Power Flow Controller (IPFC), Generalized Inter-link Power Flow Controller (GIPFC),and Hybrid Power Flow Controller (HPFC), Semi-conductor Magnetic Energy Storage (SMES), Battery Energy Storage (BESS), in power system environments for enhancement of performance parameters of power systems such as reactive power support, minimize the real power losses, improvement in voltage profile, improvement in damping ratio of power systems, provide the flexible operation and control etc. Authors strongly believe that this survey article will be very much useful for the researchers, practitioners, and scientific engineers to find out the relevant references in the field of enhancement of performance parameters of power systems by different FACTS controllers such as series, shunt, series-shunt, and series-series connected FACTS controllers are incorporated in power systems. This article is very much useful for researchers for further research work carryout in regarding with the application of FACTS controllers in power system environments for enhancement of performance parameters of systems.

Keywords

FACTS; FACTS Controllers; TCR; TSC; TCSC; SVC; TC-PAR; SSSC; STATCOM; D-STATCOM; UPFC; GUPFC; IFPC; GIPFC; and HPFC; SMES; BESS; TCBR; TSSR; Power System (PS); Performance Parameters of Systems

Nomenclatures

HVDC	High Voltage Direct Current
PSS	Power System Stabilizers
AP	Active Power
RP	Reactive Power
VSC	Voltage Source Converter
VSI	Voltage Source Inverter
VS	Voltage Stability
VI	Voltage Instability
VC	Voltage Collapse
VP	Voltage Profile
VR	Voltage Regulation
SSVS	Steady State Voltage Stability
TS	Transient Stability
APTC	Available Power Transfer Capacity
PQ	Power Quality
SSR	Sub-synchronous Resonance
OPF	Optimal Power Flow
NRFL	Newton Raphson Load Flow
FL	Fuzzy Logic
NN	Neural Network
GA	Genetic Algorithm
PSO	Particle Swarm Optimization
POD	Power Oscillation Damping
DGs	Distributed Generations
SS	Steady State
FCL	Fault Current Limiting

WP Wind Power

RESs Renewable Energy Sources

PMUs Phasor Measurement Units

Introduction

The increasing Industrialization, urbanization of life style has lead to increasing dependency on the electrical energy. This has resulted into rapid growth of PSs. This rapid growth has resulted into few uncertainties. Power disruptions and individual power outages are one of the major problems and affect the economy of any country. In contrast to the rapid changes in technologies and the power required by these technologies, transmission systems are being pushed to operate closer to their stability limits and at the same time reaching their thermal limits due to the fact that the delivery of power have been increasing. The major problems faced by power industries in establishing the match between supply and demand are:

- Transmission & Distribution; supply the electric demand without exceeding the thermal limit.
- In large PS, stability problems causing power disruptions and blackouts leading to huge losses.

These constraints affect the quality of power delivered. However, these constraints can be suppressed by enhancing the PS control. One of the best methods for reducing these constraints is FACTS devices. With the rapid development of power electronics, FACTS devices have been proposed and implemented in PSs. FACTS devices can be utilized to control power flow and enhance system stability. Particularly with the deregulation of the electricity market, there is an increasing interest in using FACTS devices in the operation and control of PSs. A better utilization of the existing PSs to increase their capacities and controllability by installing FACTS devices becomes imperative. FACTS devices are cost effective alternatives to new transmission line construction. Due to the present situation, there are two main aspects that should be considered in using FACTS devices: The first aspect is the flexible power system operation according to the power flow control capability of FACTS devices. The other aspect is the improvement of transient and SSVS of PSs. FACTS devices are the right equipment to meet these challenges.

Definition of FACTS

According to IEEE, FACTS, which is the abbreviation of *Flexible AC Transmission Systems,* is defined as follows:

"Alternating current transmission systems incorporating power electronics based and other static controllers to enhance controllability and APTC".

Since the "other static controllers" based FACTS devices are not widely used in current PSs, the focused only on the power electronics based FACTS devices. The FACTS controllers are classified as follows:

- Thyristor controlled based FACTS controllers such as TSC, TCR, FC-TCR, SVC, TCSC, TC-PAR etc.
- VSI based FACTS controllers such as SSSC, STATCOM, UPFC, GUPFC, IPFC, GIPFC, HPFC etc.

The main drawback of thyristor controlled based FACTS controllers is the resonance phenomena occurs but VSI based FACTS controllers are free from this phenomena. So that the overall performance of VSI based FACTS controllers are better than of that the thyristor controlled based FACTS controllers.

FACTS Categories and Their Functions

1) FACTS Categories

In general, FACTS devices can be divided into four categories on basis of their connection diagram in PSs mentioned in table 1:

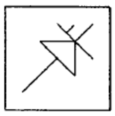
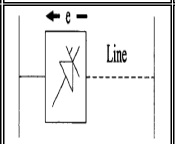
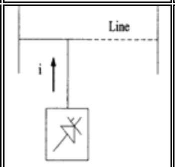
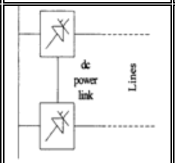
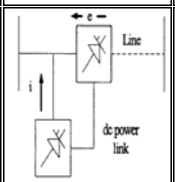
1) *Series Connected -FACTS Devices*:

Series FACTS devices could be variable impedance, such as capacitor, reactor, etc., or power electronics based variable source of main frequency, sub synchronous and harmonic frequencies (or a combination) to serve the desired need. In principle, all series FACTS devices inject voltage in series with the transmission line.

2) *Shunt Connected -FACTS Devices*:

Shunt FACTS devices may be variable impedance, variable source, or a combination of these. They inject current into the system at the point of connection.

TABLE 1 BASIC TYPE OF FACTS CONTROLLERS

No.	Symbol	Description
1		❖ General symbol for FACTS controller.
2		❖ Known as series FACTS controller such as TCSC. ❖ The controllers inject voltage in quadrature with the line current ❖ The controllers supply /absorb variable RP
3		❖ Known as shunt FACTS controller such as SVC, STATCOM. ❖ The controllers inject capacitive or inductive current in quadrature with the line voltage ❖ The controllers supply/absorb variable RP
4		❖ Known as combined series-series FACTS controller such as IPFC ❖ It is a combination of separate series controllers ❖ Provide independent series RP compensation for each line ❖ Transfer AP among the lines via the dc power link
5		❖ Known as combined series-shunt controller such as UPFC etc. ❖ It is a combination of separate series and shunt controllers ❖ Provide series and shunt RP compensation ❖ Transfer AP between the series and shunt controllers via the dc power link

3) *Combined Series-series Connected -FACTS Device*:

Combined series-series FACTS device is a combination of separate series FACTS devices, which are controlled in a coordinated manner.

4) *Combined Series-shunt Connected -FACTS Device*:

Combined series-shunt FACTS device is a combination of separate shunt and series devices, which are controlled in a coordinated manner or one device with series and shunt elements.

2) *Control Attributes for Various FACTS Controllers*

The Control Attributes for Various FACTS Controllers are shown in Table 1.2.

TABLE 2 CONTROL ATTRIBUTES FOR VARIOUS FACTS CONTROLLERS

No.	**FACTS Controller**	**Control Attributes for Various FACTS Controllers**
1	SVC, TCR, TCS, TRS	Voltage control, VAR compensation, POD, VS, TS and DS
2	TCSC, TSSC	Current control, POD, VS, TS and DS, FCL
3	TCSR, TSSR	Current control, POD, VS, TS and DS, FCL
4	TC-PST o r TC-PAR	AP control, POD, VS, TS and DS
5	TCBR	POD, TS and DS
6	TCVL	Transient and dynamic voltage limit
7	TCVR)	RP control, voltage control, POD, VS, TS and DS
8	SSSC without storage	Current control, POD, VS, TS and DS, FCL
9	SSSC with storage	Current control, POD, VS, TS and DS
10	STATCOM without storage	Voltage control, VAR compensation, POD, VS
11	STATCOM with storage, BESS, SMES, large dc capacitor	Voltage control, VAR compensation, POD, VS, TS and DS, AGC
12	UPFC	AP and RP control, voltage control, VAR compensation, POD, VS, TS and DS, FCL
13	IPFC	RP control, voltage control, POD, VS, TS and DS
14	HPFC	RP control, voltage control, POD, VS, TS and DS, FCL

3) *Possible Benefits from FACTS Technology*

Within the basic system security guidelines, the FACTS devices enable the transmission system to obtain one or more of the following benefits:

- Control of power flow as ordered. This is the main function of FACTS devices. The use of power flow control may be to follow a contract, meet the utilities' own needs, ensure optimum power flow, ride through emergency conditions, or a combination of them.

TABLE 3 APPLICATIONS OF FACTS DEVICES

Issues	Problem	Corrective Action	Conventional Solution	New Equipment (FACTS)
Voltage Limits	Low voltage at heavy load	Supply RP	Shunt capacitor, Series capacitor	TCSC, STATCOM
	High voltage at light load	Remove RP supply	Switch EHV line and/or shunt capacitor	TCSC, TCR
		Absorb RP	Switch shunt capacitor, shunt reactor, SVC	TCR, STATCOM
	High voltage following outage	Absorb RP	Add reactor	TCR
		Protect equipment	Add arrestor	TCVL
	Low voltage following outage	Supply RP limit	Switch, shunt capacitor, reactor, SVC, switch series capacitor	STATCOM, TCSC
		Prevent over load	Series reactor, PAR	IPC, TCPAR, TCSC
	Low voltage and overload;	Supply RP and limit over load	Combination of two or more equipment	IPC, TCSC, UPFC, STATCOM
Thermal Limits	Line/transformer overload	Reduce overload	Add line/transformer	TCSC, TCPAR, UPFC
			Add series reactor	TCR, IPC
	Tripping of parallel circuit	Limit circuit loading	--------------	IPC,TCR, UPFC
Short circuit levels	Excessive breaker fault current	Limit short-circuit current	Add series reactor, fuses, new circuit breaker	TCR, IPC, UPFC
		Change circuit breaker	Add new circuit breaker	
		Rearrange network	Split bus	IPC

- Increase utilization of lowest cost generation. One of the principal reasons for transmission interconnections is to utilize the lowest cost generation. When this cannot be done, it follows that there is not enough cost-effective transmission capacity. Cost-effective enhancement of capacity will therefore allow increased use of lowest cost generation.
- DS enhancement. This FACTS additional function includes the TS improvement, POD and VS control.
- Increase the loading capability of lines to their thermal capabilities, including short term and seasonal demands.
- Increased system reliability.
- Elimination or deferral of the need for new transmission lines.
- Added flexibility in siting new generation
- Provide secure tie-line connections to neighboring utilities and regions thereby decreasing overall generation reserve requirements on both sides.
- Upgrade of transmission lines.
- Increased system security.
- Reduce RP flows, thus allowing the lines to carry more AP.
- Loop flow control.

The various FACTS Controllers are proposed in literature includes First Generation [1]-[58], Second Generation [59]-[225], and Third Generation of FACTS Controllers [226]-[232].

This paper is organized as follows: Section II discusses the classification of FACTS Controllers on basis of their generation wise. Section III presents the summary of the paper. Section IV presents the conclusions of the paper.

Classification of FACTS Controllers

Three broad categories of FACTS Controllers are on basis of their generation wise such as first, second, and third generation of FACTS controllers are as follows:

First Generation of FACTS Controllers

The first generation of FACTS controllers is classified as following categories:

1) *Series Connected -FACTS Controllers:*

The series FACTS controllers are classified as following categories:

2) *TCSC*

The following performance parameter of systems as follows:

1) RP

Multi objective optimal RP flow considering FACTS technology is becoming one of the most important issues in PS planning and control. In (N. Mancer, 2012), has been presented a new variant of PSO with time varying acceleration coefficients to solve multi objective optimal RP flow (power loss minimization and voltage deviation). The proposed algorithm is used to adjust dynamically the parameters setting of TCSC in coordination with voltages of generating units.

2) VS

TCSC has been proposed to enhance the VS by changing the RP distribution in the PS. In (Garng Huang), has been discussed the effect of TCSC on SSVS and small-signal VS. Also discussed the TCSC's enhancement on transient VS. A TCSC model that is suitable for transient VS analysis is proposed in literature. The Line stability Index LSI (Gaber El-Saady, 2012) under excepted lines outage contingencies is used to identify the critical line which is considered as the best location for TCSC. A modal analysis is used to define the weakest bus of the studied system. The FACTS device is implemented and included into the NRFL algorithm, and the control function is formulated to achieve the VS enhancement goal.

3) TS

In (Siddhart Panda, 2007), has been suggested a procedure for modelling and tuning the parameters of TCSC in a multi-machine PS to improve TS. First a simple transfer function model of TCSC controller for stability improvement is developed and the parameters of the proposed controller are optimally tuned GA is employed for the optimization of the parameter-constrained nonlinear optimization problem implemented in a simulation environment. By minimizing an objective function in which the oscillatory rotor angle deviations of the generators are involved, TS performance of the system is improved. The recently has been proposed phase imbalanced series capacitive compensation (N Mohan) concept has been shown to be effective in enhancing PS dynamics as it has the potential of damping power swing as well as sub synchronous resonance oscillations. The effectiveness of a "hybrid" series capacitive compensation scheme in POD is evaluated. A hybrid scheme is a series capacitive compensation scheme, where two phases are compensated by fixed series capacitor and the third phase is compensated by a TCSC in series with a fixed capacitor. The SSR phenomenon may occur when a steam turbine-generator is connected to a long transmission line with series compensation. FACTS devices are widely applied to damp the SSR and Low-Frequency Oscillation (LFO). TCSC is a commercially available FACTS device which developed for damping the SSR and LFO. In (Hasan Ghahramani), has been proposed the two control methods for damping the SSR and LFO are added to the TCSC main controller in order to demonstrate that the SSR damping capability of TCSC can be enhanced by proper modulation of firing angle. The control methods are presented, namely: Conventional Damping Controller (CDC) and FL Damping Controller (FLDC). PSO algorithm is used for searching optimized parameters of the CDC. Fast Fourier Transform (FFT) is carried out in order to evaluate effect of the TCSC based FLDC in damping the SSR and LFO. In (Nelson Martins), has been described, in a tutorial manner, TCSC control aspects illustrated through simulation results on a small power system benchmark model. The analysis and design of the TCSC controls, to schedule line power and damp system oscillations, are based on modal analysis, and time and frequency response techniques. Root locus plots are also utilized. The impact of badly located zeros on the system transient response is assessed and possible solutions are proposed. Optimal supplementary damping controller design for TCSC is presented in (S. Panda, 2009), the proposed controller design, a multi-objective fitness function consisting of both damping factors and real part of system electro-mechanical Eigen-value is used and Real-Coded GA is employed for the optimal supplementary controller parameters. TCSC, a prominent FACTS device, can rapidly modulate the impedance of a transmission line, resulting in improvement of system performance. The purposed of the work

reported in (Ning Yang, 1995) is to design a controller to damp inter-area oscillations. We have applied the residue method to the linearized form which is suitable for different controller input/output channels and therefore suitable for different control devices. In (Ch. Venkatesh, 2010), has been presented a different viewpoint of flatness which uses a coordinate change based on a Lie-Backlund approach to equivalence in developing flatness-based feedback linearization and its application to the design of model predictive control based FACTS controller for power system transient stability improvement. In (Nelson Martins, 2000),has been described, in a tutorial manner, TCSC control aspects illustrated through simulation results on a small PS model. The analysis and design of the TCSC controls, to schedule line power and damp system oscillations, are based on modal analysis. and time and frequency response techniques.

4) SSVS

Different control aspects related to the use of TCSC for stability improvement of PSs are addressed in (Alberto D. Del Rosso, 2003). A novel hierarchical control designed for both DS and SSVS enhancement is proposed, and a complete analysis is presented of various locally measurable input signals that can be used for the controller. Control strategies to mitigate adverse interactions among the TCSC hierarchical controls are also presented. In (Tain-Syh Luo, 1998), an output feedback variable structure controller is designed for a TCSC in order to improve the damping characteristic of a PS. Physically measurable AR and RP signals near TCSC locations are used as the inputs to the variable structure controller. These input signals are employed to construct the switching hyper plane of the proposed variable structure TCSC controller.

5) Flexible Operation and Control

There are two types of FACTS controller's viz. series and shunt. Series compensation reduces the transmission line reactance in order to improve Power Flow through it, while shunt compensation improves the Voltage profile. Among the FACTS devices, the TCSC controller has tremendous capability of giving the best results in terms of performance. In (Venu Yarlagadda, 2012) – (S.Panda, 2005), developed the control algorithm for automatic control for the developed working model of TCSC. The investigated the effects of TCSC on synchronous stability and VS improvement. Stability of the System has been assessed using P-ẟ and P-V Curves.

6) Protection

In (Arunachalam, 2005), has been described the evaluation of the performance of the controller developed by Bharat Heavy Electricals Limited (BHEL) for TCSC using Real Time Digital Simulator. The TCSC controller was developed for the Kanpur-Ballabhgarh 400kV single circuit ac transmission line located in North India. It is designed to perform important functions like impedance control, current control in the line and damping of power swing oscillation caused by system disturbances. It also reduces the stress on Metal Oxide Varistor during faults and protects the capacitor against overvoltage and the TCR against over current. In (P. S. Chaudhari)- (Mrs. P A Kulkarni, 2010), has been presented a grid of transmission lines operating at high or extra high voltages is required to transmit power from generating stations to load. In addition to transmission lines that carry power from source to load, modern power systems are highly interconnected for economic reasons. The large interconnected transmission networks are prone to faults due to the lightning discharges and reduce insulation strength. Changing loads and atmospheric conditions are unpredictable factors. This may cause overloading of lines due to which VC takes place. All the above said things are undesirable for secure and economic operation of a line. These problems can be eased by providing sufficient margin of working parameters and power transfer, but it is not possible due to expansion of transmission network. Still the required margin is reduced by introduction of fast dynamic control over RP and AP by high power electronic controllers. Modern PSs are designed to operate efficiently to supply power on demand to various load centres with high reliability. The generating stations are often located at distant locations for economic, environmental and for safety reasons. Thus a grid of transmission lines operating at high or extra high voltages is required to transmit power from generating stations to load. In addition to transmission lines that carry power from source to load, modern power systems are highly interconnected for economic reasons. Its benefit is exploiting load diversity, sharing of

generation reserves, and economy. The large interconnected transmission networks are prone to faults due to the lightning discharges and reduces insulation strength. changing loads and atmospheric conditions are unpredictable factors. This may cause overloading of lines due to which voltage collapse takes place. All the above said things are undesirable for secure and economic operation of a line. These problems can be eased by providing sufficient margin of working parameters and power transfer, but it is not possible due to expansion of transmission network. Still the required margin is reduced by introduction of fast dynamic control over RP and AP by high power electronic controllers. This can make AC transmission network flexible. This FACTS they are alternating current transmission systems incorporating power electronic based and other static controllers to enhance controllability and increase APTC. Hence FACTS controller is defined as power electronic based system and other static equipment that provide control of one or more AC transmission system parameters.

7) APTC

In (Ibraheem, 2011), an attempt has been made to determined ATC with the FACTS device i.e. TCSC. The methods for ATC evaluation are developed considering system thermal limits constraints based on MVA loading of the system. Power Transfer Distribution Factors are used to determine the maximum ATC that may be available across the system in a certain direction without violating line thermal limits. ATC traditionally uses linear methods capable of predicting distances based on thermal limits. However, these methods do not consider bus voltages and static collapse.

8) Optimal Location

PS stability improvement by a coordinate Design of TCSC controller is addressed in (Swathi kommamuri, 2011). PSO technique is employed for optimization of the parameter constrained nonlinear optimization problem implemented in a simulation environment. In (Abouzar Samimi, 2012), a new method has been proposed to determine optimal location and best setting of TCSC. Seeking the best place is performed using the sensitivity analysis and optimum setting of TCSC is managed using the GA. The configuration of a typical TCSC from a SS perspective is the fixed capacitor with a TCR. The effect of TCSC on the network can be modeled as a controllable reactance inserted in the related transmission line.

9) Others

PS engineers (Preeti Singh, 2008) are currently facing challenges to increase the power transfer capabilities of existing transmission system. This is where the FACTS technology comes into effect. With relatively low investment, compared to new transmission or generation facilities, the FACTS technology allows the industries to better utilize the existing transmission and generation reserves, while enhancing the PS performance. Moreover, the current trend of deregulated electricity market also favours the FACTS controllers in many ways. FACTS controllers in the deregulated electricity market allow the system to be used in more flexible way with increase in various stability margins. FACTS controllers are products of FACTS technology; a group of power electronics controllers expected to revolutionize the power transmission and distribution system in many ways. The FACTS controllers clearly enhance PS performance, improve quality of supply and also provide an optimal utilization of the existing resources. TCSC is a key FACTS controller and is widely recognized as an effective and economical means to enhance PS stability. For transmission of large amounts of electric power, AC in the overwhelming majority of cases is the established as well as the most cost effective option at hand. In cases of long distance transmission, as in interconnection of PSs, care has to be taken for safeguarding of synchronism as well as stable system voltages in the interconnection, particularly for extreme load conditions and in conjunction with system faults. Use of TCSC as FACTS device brings a number of benefits for the user of the grid, all contributing to an increase of the power transmission capability of new as well as existing transmission lines. These benefits include improvement in system stability, voltage regulation, RP balance, load sharing between parallel lines and reduction in transmission losses (Md. Nasimul Islam, 2010).

3) TC-PAR

The following performance parameter of systems as follows:

1) AP

In (Ashwani Kumar Sharma, 2008),congestion clusters based on modified AP flow sensitivity

factors considering effect of slack bus for congestion management scheme has been proposed. The most sensitive congestion clusters will provide important information to system operator to select the generators from selected sensitive zone to reschedule their generation for transmission congestion management more efficiently. The impact of TC-PAR has also been investigated on congestion clusters and congestion cost and their optimal placement have been obtained using mixed integer programming approach.

2) *TS*

A robust damping control design methodology for a TC-PAR using global signals is proposed based on the simultaneous stabilisation approach. The numerical design algorithm determines the controller parameters in order to guarantee closed-loop poles in the left half plane with preferential treatment to those corresponding to the inter-area modes. Plant models under different operating conditions are incorporated in the design formulation to achieve the desired performance robustness. A three-input/single-output controller is designed for the TC-PAR to provide adequate damping to the critical inter-area modes of a study system model. Based on the observability of the inter-area modes, AP flows from remote locations are used as feedback stabilising signals. The damping performance of the controller is examined in the frequency and time domains and is found to be robust against varying power-flow patterns nature of loads, tie-line strengths and system non-linearities, including saturation (B.C. Pal, B. Chaudhuri, 2004).

3) *Flexible Operation and Control*

FACTS device like TC-PAR can be used to regulate the power flow in the tie-lines of interconnected PS. When TC-PAR is equipped with power regulator and frequency based stabiliser it can also significantly influence the power flow in the transient states occurring after power disturbances. In the case of simple interconnected PS, consisting of two power systems the control of TC-PAR can force a good damping of both power swings and oscillations of local frequency. In the case of larger interconnected PS consisting of more than two PSs the influence of the control of TC-PAR on damping can be more complicated. Strong damping of LFOs and power swings in one tie-line may cause larger oscillations in remote tie-lines and other systems. Hence using devices like TC-PAR as a tool for damping of power swings and frequency oscillations in a large interconnected PS must be justified by detailed analysis of PS dynamics (] D.D. Rasolomampionona, 2003)

4) *APTC*

The ATC of a transmission system is a measure of unutilized capability of the system at a given time. The computation of ATC is very important to the transmission system security and market forecasting. While the power marketers are focusing on fully utilizing the transmission system, engineers are concern with the transmission system security as any power transfers over the limit might result in system instability. One of the most critical issues that any engineers would like to keep an eye on is the VC. Recent blackouts in major cities throughout the world have raised concerns about the VC phenomenon. FACTS devices such as TCSC and TC-PAR, by controlling the power flows in the network, can help to reduce the flows in heavily loaded lines resulting in an increased loadability of the network and improves the VS (k. Narasimha rao, 2007)

5) *Others*

In (B.C. Pal, 2004) has been discussed a robust damping control design methodology for a TC-PAR using global signals is proposed based on the simultaneous stabilisation approach. The numerical design algorithm determines the controller parameters in order to guarantee closed-loop poles in the left half plane with preferential treatment to those corresponding to the inter-area modes. Plant models under different operating conditions are incorporated in the design formulation to achieve the desired performance robustness. A three-input/single-output controller is designed for the TC-PAR to provide adequate damping to the critical inter-area modes of a study system model. In (A. Kuma1, 2000), a scheme based on generators and loads real and RP flow contribution factors has been presented for congestion management in pool based electricity markets. The system operator (SO) can identify the generators and loads based on these contribution factors for rescheduling their real and RP generation and loads to manage congestion. The AP and RP bid curves for both generators and loads have been incorporated in the optimization

model to determine congestion cost. The impact of TC-PAR has also been determined on the congestion cost. In (A. Kumar, 2008), transmission congestion distribution factors based on sensitivity of line real power flow and full AC load flow Jacobian sensitivity have been proposed to identify the congestion clusters. The system operator can identify the generators from the most sensitive congestion clusters to reschedule their generation optimally to manage transmission congestion efficiently. The role of TC-PAR has been investigated for reducing the transmission congestion cost after locating it optimally in the system based on improved performance index.

4) TCR-FC

The following performance parameters of systems as follows:

1) RP Flow Control

In (T. Vijayakumar, 2011), has been discussed with the simulation of eight bus system having fixed capacitor and TCR. The system is modeled and simulated using MATLAB. In (T.Vijayakumar, 2009) ,has been discussed the simulation of FC-TSR-TCR system.

2) Voltage

In (Muzunoglu, 2005), non-sinusoidal quantities and VS, both known as PQ criteria, are examined together in detail. The widespread use of power electronics elements causes the existence of significant non-sinusoidal quantities in the system. These non-sinusoidal quantities can create serious harmonic distortions in transmission and distribution systems. The harmonic generation of a SVC with TCR and effects of the harmonics on SSVS are examined for various operational conditions.

3) TS

In FACTS devices (Sonal Jain) various auxiliary signal are used for POD. These signals may be Deviation in AP, RP to TCR-FC bus, Deviation in frequency, derivative of AP, RP etc.

4) Others

In (Cláudio H., 2008), has been presented a study on the application of FC, TCRs. A self-supplied thyristor firing circuit is considered, which can be used in medium to high power applications, avoiding the use of multiple isolated power supplies. In (Jyoti Agrawal, 2011), has been addressed the simulation of TCR and GTO Controlled Series Capacitor (GCSC), equipment for controlled series compensation of transmission systems. TCR-FC (Vipin Jain), is a well known combination to improve VS. Supplementary signals such as variation in RP, variation in frequency is used to enhance the dynamic response of the system. Harmonics that arise from the interaction of TCRs (T.Vijayakumar, 2010) and PSs are difficult to analyze. Two methods are described. The first develops a Fourier matrix model for the TCR. The coupling between the harmonics through the system impedance is clearly shown. The second method uses state variable analysis to write the system equations for a circuit containing a TCR. The systems of equations that result are linear with time varying coefficients. Using linear system theory statements and resonance can be made. In () has been suggested the simulation and implementation of FC-TCR system.

Electric Arc Furnaces (EAFs) are unbalanced, nonlinear and time varying loads, which can cause many problems in the PQ. As the use of arc furnace loads increases in industry, the importance of the PQ problems also increase. So in order to optimize the usages of electric power in EAFs, it is necessary to minimize the effects of arc furnace loads on PQ in PSs as much as possible. Then by considering the high changes of RP and VF of nonlinear furnace load, TCR compensation with FC are designed and simulated. In this procedure, the RP is measured so that maximum speed and accuracy are achieved (Rahmat Allah, 2009).

5) Shunt Connected-FACTS Controllers

The following shunt connected FACTS controllers are as follows:

6) SVC

The following performance parameters of systems as follows:

1) Voltage Profile

However, in previous study the effect of SVC and PSS on voltage transient in PS with suitable model of these component for various faults such as Single Line to Ground faults (SLG) and Line to line and Line to Line to Ground (LL and LLG) and three phase faults have not been considered and analysed and investigated. Shunt FACTS devices,

when placed at the mid-point of along transmission line, play an important role in controlling the RP to the power network and hence both the system VS and TS. This study deals with the location of a shunt FACTS device to improve TS in along transmission line with pre defined direction of AP flow. The validity of the mid-point location of shunt FACTS devices is verified, with various shunt FACTS devices, namely SVC in a long transmission line using the actual line model (Mohammad Mohammadi, 2011). In emerging electric PSs, increased transactions often lead to the situations where the system no longer remains in secure operating region. The FACTS controllers can play an important role in the PS security enhancement. However, due to high capital investment, it is necessary to locate these controllers optimally in the PS. FACTS devices can regulate the AP and RP power control as well as adaptive to voltage-magnitude control simultaneously because of their flexibility and fast control characteristics. Placement of these devices in suitable location can lead to control in line flow and maintain bus voltages in desired level and so improve VS margins. The proposed a systematic method by which optimal location of multi-type FACTS devices to be installed (Ch.Rambabu). VI and VC (Kalaivani, R., 2012) have been considered as a major threat to present PS networks due to their stressed operation. It is very important to do the PS analysis with respect to VS. *Approach:* FACTS is an alternating current transmission system incorporating power electronic-based and other static controllers to enhance controllability and increase APTC. A FACTS device in a PS improves the VS, reduces the power loss and also improves the load ability of the system. *Results:* This study investigates the application of PSO and GA to find optimal location and rated value of SVC device to minimize the VS index, total power loss, load voltage deviation, cost of generation and cost of FACTS devices to improve VS in the PS. Optimal location and rated value of SVC device have been found in different loading scenario (115%, 125% and 150% of normal loading) using PSO and GA. In (Roberto Alves), has been presented an application of a SVC. A SVC is one of the controllers based on Power Electronics and other static devices known as FACTS devices which it could be used to increase the capacity and the flexibility of a transmission network. The system under study is an interconnected network located in the southeast region of Venezuela. The objective of our study was to increase the power flow, under the thermal capacity, through an overhead transmission lines, using a VS approach.

2) TS

A prospective application of applying an adaptive controller to a SVC to damp power system oscillations and enhance system stability is presented in (A. Albakkar, 2010).

3) SSVS

In (Claudio A. Ca˜nizares), has been discussed the effect on transmission congestion management and pricing of dynamic and steady state models of FACTS controllers. The analysis is based on comparing system operating conditions and locational marginal prices obtained from stability-constrained auction models when dynamic and steady state FACTS models are used. A novel stability-constrained OPF auction model, which allows for the inclusion of dynamic models of PSs elements, including FACTS controllers, and a better representation of system stability constraints, is described in some detail and applied to the IEEE 14-bus benchmark system with a SVC.

***4)* Testing and Control**

Implemented a small scale laboratory based TSC-TCR type SVC. The automatic control circuit has been implemented using microcontroller and tested with the Single Machine Two Bus Test system without and with SVC (Venu Yarlagadda, 2012).

5) Protection

As open transmission access is becoming a reality, a major concern of electric power utilities is to maintain the reliability of the grid. Increased power transfers raise concerns about steady-state overloads, increased risks of VC, and potential stability problems. Strengthening the protection and control strategies is what utilities must do to prevent a local problem from spreading to other parts of the grid (Venu Yarlagadda. 2012).

***6)* Optimal Location *of* FACTS Controllers**

In (Roberto Mínguez, 2007), has been addressed the optimal placement of SVCs in a transmission network in such a manner that its loading margin

is maximized. A multi-scenario framework that includes contingencies is considered. A PS, under heavily loaded conditions, is at high risks of probable line outage and consequent VI problem. Real power loss and voltage deviation minimization are reliable indicators of voltage security of power networks. In (S.Sakthivel, 2011) ,has been addressed a PSO based optimal location and sizing of SVC to improve VS under the most critical line outage contingency in a PS network. Line outages are ranked based on increased RP generation and line losses.

7) Others

Elmhurst Substation is located in Commonwealth Edison's (ComEd's) Northeast subzone. To support reliability in that area of the system when synchronous condensers that have been in operation in the region are retired, two identical 300 MVAr SVCs were installed at the Elmhurst Substation. Each SVC consists of three TSCs rated at 75 MVAr (TSC1), 75 MVAr (TSC2), and 150 MVAr (TSC3). In (Lutz Kirschner), has been provided details of the two identical 300 MVAr SVCs operating in parallel; it illustrates the background of system needs for dynamic RP support, the designed structure as well as the control and protection system of the two SVCs. In (Alisha Banga, 2011)- (E Barocio, 2002) discussed and demonstrated how SVC has successfully been applied to control transmission systems dynamic performance for system disturbance and effectively regulate system voltage. SVC is basically a shunt connected SVC whose output is adjusted to exchange capacitive or inductive current so as to maintain or control specific power variable; typically, the control variable is the SVC bus voltage. One of the major reasons for installing a SVC is to improve dynamic voltage control and thus increase system loadability.

Combined-FACTS Controllers

1) TCSC and SVC

1) AP and RP

Modern day PS networks (L.Jebaraj, 2012) are having high risks of VI problems and several network blackouts have been reported. This phenomenon tends to occur from lack of RP supports in heavily stressed operating conditions caused by increased load demand and the fast developing deregulation of PSs across the world. In (JJ. V. Parate, 2012), has been proposed an application of Differential Evolution (DE) Algorithm based extended VS margin and minimization of loss by incorporating TCSC and SVC (variable susceptance model) devices. The line stability index (LQP) is used to assess the voltage stability of a power system. The location and size of Series connected and Shunt connected FACTS devices were optimized by DE algorithm. In general the problem of RP control is viewed from two aspects: load compensation and voltage support. This is utilized to reduce the total system AP loss or voltage deviation as an objective to compute optimal settings of RP output or terminal voltages of generating plants, transformer tap settings and output of other compensating devices such as capacitor banks and synchronous condensers.

2) APTC

Increased electric power consumption causes transmission lines to be driven close to or even beyond their transfer capacities resulting in overloaded lines and congestions. FACTS provide an opportunity to resolve congestions by controlling power flows and voltages. In general, SVCs and TCSCs are controlled locally without any coordination (G. Glanzmann). Improving ATC is important in the current deregulated environment of PSs. In (K.Venkateswarlu, 2012) , ATC is computed using Continuous Power Flow (CPF) method considering line thermal limit and bus voltage limits. FACTS can control magnitude of voltage, phase angle and circuit reactance and the load flow may be re-distributed to regulate bus voltages. Real-code Genetic Algorithm (RGA) is used as the optimization tool to determine the location and the controlling parameters of FACTs devices. Total Transfer Capability (TTC) forms the basis for ATC. ATC of a transmission system is a measure of unutilized capability of a system at a given time. The computation of ATC is very important to transmission system security and market forecasting this paper focuses on the evaluation of impact of TCSC and SVC as FACTS devices on ATC and its enhancement. The optimal location of FACTS devices were determined based on Sensitivity methods. The Reduction of Total System RP Losses Method was used to determine the suitable location of TCSC and SVC for ATC enhancement (G. Swapna1, 2012).

Second Generation of FACTS Controllers

The second generation of FACTS controllers is classified as following categories:

Series Connected FACTS Controllers

1) SSSC

The following performance parameters of systems as follows:

1) AP

Recent day PS networks are having high risks of VI problems and several network blackouts have been reported. This phenomenon tends to occur from lack of RP supports in heavily stressed operating conditions caused by increased load demand and the fast developing deregulation of PSs across the world. In (L. Jebaraj, 2012), has been proposed an application of Shuffled Frog Leaping Algorithm (SFLA) based extended VS margin and minimization of loss by incorporating SSSC and SVC (variable susceptance model) devices. A new circuit elements based model of SSSC is utilized to control the line power flows and bus voltage magnitudes for VS limit improvement. The new model of the SSSC changes only the bus admittance matrix and consequently reduces the coding of load flow problem incorporating SSSC simple. The line stability index (LQP) is used to assess the VS of a PS. The location and size of Series connected and Shunt connected FACTS devices were optimized by shuffled frog leaping algorithm.

2) RP

A transmission line needs controllable compensation for power flow control and voltage regulation. This can be achieved by FACTS controllers. SSSC is a series connected FACTS controller, which is capable of providing RP compensation to a PS. The output of an SSSC is series injected voltage, which leads or lags line current by 90°, thus emulating a controllable inductive or capacitive reactance. SSSC can be used to reduce the equivalent line impedance and enhance the active APTC of the line (Chintan R Patel).

3) Voltage

The maintenance and availability of the PS can be considered a major aspect of investigation. The encouragement to the planning of HV lines, the value of power that transfer per km on HV line and the amount of power transaction as seen from economic side is much responsible for concern towards congestion phenomena in power system. The idea for solving this problem is the use of FACTS devices especially the use of SSSC (Hossein Nasir Aghdam, 2011).

4) TS

Reference (A. Kazem, 2005), a new GA is proposed for optimal selection of the SSSC damping controller parameters in order to shift the closed loop eigenvalues toward the desired stability region. Controller design is formulated as a nonlinear constrained optimization problem. As the combination of objective function (system stability) and constraints (limits of controller gains) is used as the fitness function, their simultaneous improvement is achieved.

Problem statement (Sona Padma, 2011): FACTS devices play a major role in the efficient operation of the complex PS. FACTS devices such as STATCOM, SSSC and IPFC are in increasing usage. With energy storage systems they have a good control over the real as well as RP compensation and TS improvement. The design of controller for the SSSC with SMES system is analyzed in this study. *Approach:* The main variables to be controlled in the PS for efficient operation are the voltage, phase angle and impedance. A SSSC is a series connected converter based FACTS control which can provide a series RP compensation for a transmission system. With the addition of energy storage device, in addition to the RP compensation the AP exchange is also accomplished. FL controller is designed for the efficient operation of the PS with SSSC integrated with energy storage device. From the power reference the current reference is calculated and the error and change in error in the current are calculated in the controller. *Results:* A three phase to ground fault is simulated in the test system. A comparative analysis of the PI and FL control of SSSC with energy storage system for the rotor angle oscillation damping following the disturbance is done. In (Sidhartha Panda, 2007), the application of a SSSC controller to improve the TS performance of a PS is thoroughly investigated. The design problem of SSSC controller is formulated as an optimization problem and PSO Technique is employed to search for optimal controller parameters. By minimizing the time-domain based objective function, in which the

deviation in the oscillatory rotor angle of the generator is involved; TS performance of the system is improved.

5) PS Stability

In (S Arun Kumar, 2012), has been investigated the enhancement of VS using SSSC. The continuous demand in electric PS network has caused the system to be heavily loaded leading to VI. Under heavy loaded conditions there may be insufficient RP causing the voltages to drop. This drop may lead to drops in voltage at various buses. The result would be the occurrence of VC which leads to total blackout of the whole system. FACTS controllers have been mainly used for solving various PS stability control problems. In this study, a SSSC is used to investigate the effect of this device in controlling AP and RP as well as damping power system oscillations in transient mode.

6) Flexible Operation and Control

The main aim of (D. Murali, 2010), has been to damp out PS oscillations, which has been recognized as one of the major concerns in PS operation. The described the damping of power oscillations by hybrid neuro-fuzzy coordinated control of FACTS based damping controllers. The advantage of this approach is that it can handle the nonlinearities, at the same time it is faster than other conventional controllers. ANFIS (Adaptive Neuro-Fuzzy Inference System) is employed for the training of the proposed FL controllers.

7) APTC

SSSC is a VSC based series FACTS device that provides capacitive or inductive compensation independent of line current. In (Akhilesh A. Nimje, 2011), has been presented the achievement of the required AP and RP flow into the line for the purpose of compensation as well as validation of enhancement of the APTC of a transmission line when IPFC acts as standalone as SSSC. The effect of variation of the phase angle of the injected voltage on the PS parameters such as effective sending end voltage, effective transmission angle, AP, RP, and overall power factor with and without SSSC have also been incorporated. In (Sh. Javadi, 2011), has been reviewed the optimization ATC of PSs using a device of FACTS named SSSC equipped with energy storage devices. So that, emplacement and improvement of parameters of SSSC will be illustrated. Thus, voltage magnitude constraints of network buses, line TS constraints and voltage breakdown constraints are considered.

8) Optimization Techniques

The aim of (Seyed M.H Nabavi, 2011), has been presented a GA based method for congestion management and to maximize social welfare using one unit SSSC in a double auction pool market based PSs. The aims are achieved by optimal locating and sizing one SSSC unit. In (Sidhartha Panda, 2007), has been presented a GA optimization technique is applied to design FACTS based damping controllers. Two types of controller structures, namely a proportional-integral (PI) and a lead-lag (LL) are considered.

9) Others

In (R. Thirumalaivasan, 2011), investigation of SSR characteristics of a hybrid series compensated system and the design of voltage controller for three level 24-pulse VSC based SSSC is presented. Hybrid compensation consists of series fixed capacitor and SSSC which is a active series FACTS controller. In (Anju Meghwani, 2008), presented the implementation of SSSC controller on Real Time Application Interface (RTAI) for Linux Operating System (OS). RTAI provides real-time capability to Linux General Purpose Operating System (GPOS) over and above the capabilities of non real-time Linux environment, e.g. access to TCP/IP, graphical display and windowing systems, file and database systems. Both Type II controllers, DC voltage and current scheduling controllers, are implemented in RTAI. To create a user friendly environment, Graphical User Interface (GUI) is developed in Linux OS in user space (non real-time) using a software available from Quasar Technologies (Qt). In (Sidhartha Panda, 2010), a systematic procedure for modeling, simulation and optimally tuning the parameters of a SSSC controller in a multi-machine system, for PS stability enhancement is presented.

Series–Series Connected FACTS Controllers

1) IPFC

The following performance parameters of systems as follows:

1) AP and RP

The IPFC (Laszlo Gyugyi, 1999), has been proposed is a new concept for the compensation and

effective power flow management of multiline transmission systems. In its general form, the IPFC employs a number of inverters with a common dc link, each to provide series compensation for a selected line of the transmission system. Since each inverter is also able to provide RP compensation, the IPFC is able to carry out an overall AP and RP compensation of the total transmission system. This capability makes it possible to equalize both AP and RP flow between the lines, transfer power from loaded to unloaded lines, compensate against reactive voltage drop sand the corresponding reactive line power, and to increase the effectiveness of the compensating system against dynamic disturbances.

2) TS

The effect of an IPFC (A. Kazemi, 2008) on damping LFO has been implied in many literatures, but has not been investigated in detail. A considerable progress has been achieved in TS analysis with various FACTS controllers. But, all these controllers are associated with single transmission line. In (A.V.Naresh Babu, 2012), discussed a new approach i.e. a multi-line FACTS controller which is IPFC for TSA of a multi-machine PS network. A mathematical model of IPFC, termed as power injection model presented and this model is incorporated in NRFL algorithm.

3) SSVS

The IPFC main advantages and limitations whilst controlling simultaneously the power flow in multiline systems are presented in reference in (R.L. Vasquez, 2008).

4) Flexible Operation and Control

Electrical energy is transported from the generating point (D.Lakshman Kumar, 2012) to the point of use through interconnected transmission lines. The flow of electricity through the transmission lines can be effectively and efficiently controlled by using IPFC instead of going for a new transmission lines. IPFC (B. Karthik, 2011) are commonly used for maintaining power flow in the multiline transmission lines and to increase the AP in the line. The main problem here is the identification of a proper place for fixing the IPFC in the transmission system. Here, we proposed a hybrid technique for identifying the proper place for fixing the IPFC. The proposed hybrid technique utilizes GA and NN to identify the proper place for fixing the IPFC. The training dataset is generated using the GA. In (G. Irusapparajan, 2011), has been dealed with experimental verification of IPFC. IPFC is a Concept of FACTS controller with the unique capability for series compensation with the unique capability of power flow management among multi-line of a substation.

5) APTC

In (A.V. Naresh Babu1, 2012), presented the use of an advanced and versatile member of FACTS device which is IPFC to improve the ATC. In general, IPFC is used in multiple transmission lines of a PS network. A mathematical model of IPFC, termed as power injection model is derived.

6) Optimization Techniques

In (A. V. Naresh Babu, 2012)-(Jianhong Chen, 2002), a new intelligent search evolution algorithm (ISEA) is proposed to minimize the generator fuel cost in OPF control with multi-line FACTS device which is IPFC.

7) Others

The IPFC (A. P.Usha Rani, 2010) is a VSC based FACTS controller for series compensation with the unique capability of power flow management among the multiline transmission systems of a substation. The RP injected by individual VSC can be controlled to regulate AP flow in the respective line. While one VSC regulates the DC voltage, the other one controls the RP flows in the lines by injecting series active voltage. The IPFC is among the FACTS devices aimed at simultaneously controlling the power flow in multiline systems (B. Karthik and S. Chandrasekar, 2012). The Separated IPFC (B. Karthik and S. Chandrasekar, 2011), presented is a new concept for a FACTS device. The S-IPFC is an adapted version of the IPFC, which eliminates the common DC link of the IPFC and enable the separate installation of the converters. Without location constrain, more power lines can be equipped with the S-IPFC, which gives more control capability of the power flow control. Instead of the common dc link, the exchange AP between the converters is through the same ac transmission line at 3rd harmonic frequency. Every converter has its own dc capacitor to provide the dc voltage.

8) GIPFC

A GIPFC (Mahesh Hanumantha Prabhu) is an emerging FACTS based controller that provides

better stability, better controllability and enhanced power flow between the interconnected transmission lines by exchanging the AP and RP flow between interconnected transmission lines. To maintain the desired power flow in all the transmission lines of the interconnected system, a shunt converter and a number of series converters are used.

Series–Shunt Connected-FACTS Controllers

1) UPFC

The following performance parameters of systems as follows:

1) AP and RP

FACTS technology (D. Murali, 2010) opens up new opportunities for controlling power and enhancing the usable capacity of present, as well as new and upgraded lines. The UPFC is a second generation FACTS device which enables independent control of AP and RP besides improving reliability and quality of the supply. Reference ((Marouani I, Guesmi T), the optimal location and sizing of UPFC is found in order to solve the optimal reactive power dispatch (ORPD). The ORPD was been formulated as a minimization of total system transmission loss and improvement of VP. To solve this multi-objective optimization problem an elitist multi-objective evolutionary algorithm based on non-dominated sorting genetic algorithm II (NSGAII) is used. The UPFC is the most versatile and complex power electronic equipment that has emerged for the control and optimization of power flow in electrical power transmission system. In (S. Tara Kalyani, 2008), presented the AP and RP flow control through a transmission line by placing UPFC at the sending end using computer simulation. When no UPFC is installed, AP and RP through the transmission line can not be controlled. Reference (L.Gyugyi, 1992), discussed the UPFC is able to control the transmitted real power and independently the RP flows at the sending and the receiving end of the transmission line. The unique capabilities of the UPFC in multiple line compensation are integrated into a generalized power controller, AP and RP flow in the line.

2) VS

A critical factor effecting power transmission systems today is power flow control. The increment of load variation in a power transmission system can lead to potential failure on the entire system as the system has to work under a stressed condition. Thus, the FACTS are integrated in PS to control the power flow in specific lines and improve the security of transmission line. In (Nor Rul Hasma Abdullah Ismail Musirin, 2010), presented an Evolutionary Programming (EP) techniques for solving RP problem incorporating UPFC. The objective of the study is to employ EP optimization technique for loss minimization along with installation cost calculation and VP monitoring. The optimizations are made based on two parameters: the location of the devices and it sizes. The UPFC devices are installed in the system in order to enhance the system security; performed on the IEEE 30-bus RTS for several loading conditions.

3) TS

In (A.Kazemi, 2004), has been presented a hybrid method on investigation of UPFC effects on TS of multi machine PS has been introduced. Based on the combination of output results of time domain simulation and transient energy function (TEF) analysis, study of PS-TS is converted to the study of TS of only one machine, so called critical machine. The effects of UPFC in three basic control mode namely in-phase voltage control, quadrature voltage control and shunt compensation control on the TS margin and for various fault clearing times, has been studied. Reference (P. K. Dash, 2004), presented the design of a nonlinear variable-gain FL controller for a FACTS device like the UPFC to enhance the TS performance of PSs With the growing demand of electricity, at times, it is not possible to erect new lines to face the situation. FACTS use the thyristor controlled devices and optimally utilizes the existing power network. FACTS devices play an important role in controlling the RP and AP flow to the power network and hence both the system voltage fluctuations and TS. In (A. Elkholy, 2010), has been proposed the UPFC as a power electronic based device that has capability of controlling the power flow through the line by controlling its series and shunt converters, also combined with DGs connected in the DC link to mitigate PQ disturbances. Reference (J. Jegatheesan, 2011), an adaptive UPFC is designed with the application of the intelligent techniques such as a combination of NN and FL has been presented. Reference (Claudio Cañizares, 2004), described and validated

a TS and power flow model of a UPFC, and presented a detailed comparison of different controls strategies, proposing novel, efficient and simple controls for this controller. The proposed model accurately represents the behavior of the controller in quasi-steady state operating conditions, and hence is adequate for TS as well as SSVS analyses of PSs.

4) *SSVS*

In (S.Ali Al-Mawsawi, 2012), a new developed construction model of the UPFC is proposed. The construction of this model consists of one shunt compensation block and two series compensation blocks. In this case, the UPFC with the new construction model will be investigated when it is installed in multi-machine systems with nonlinear load model. Reference (A.M. Vural, 2003), presented an improved SS mathematical model for UPFC, which is necessary for the analysis of the SS operation of this device embedded in a PS. The model is based on the concept of injected powers in which the operational losses can be taken into account.

5) *Flexible Operation and control*

FACTS (Bhanu Chennapragada, 2003) technology opens up new opportunities for controlling power and enhancing the usable capacity of present, as well as new and upgraded lines. The UPFC is a second generation FACTS device, which enables independent control of AP and RP besides improving reliability and quality of the supply.

6) *Protection*

The presence of an important of FACTS (P.K. Dash, 2000) device like UPFC can drastically affect the performance of a distance relay in a two-terminal system connected by a double-circuit transmission line. The control characteristics of the UPFC, its location on the transmission system and the fault resistance, especially the high ones make this problem more severe and complicated. Reference (T. Manokaran), presented a simulation results of the application of distance relays for the protection of transmission systems employing FACTS such as the UPFC.

7) *APTC*

In (Ashwani Kumar, 2008), has been addressed a mixed integer programming based approach for optimal placement of DC model of UPFC in the deregulated electricity environment. The method accounts for DC load flow equations taking constraints on generation, line flow, and UPFC parameters. The security of transactions has become important issue to reserve the APTC.

8) *Optimal Location of FACTS Controllers*

In (Prakash Burade, 2012), a UPFC is a FACTS device that can be control the power flow in transmission line by injecting active and reactive in voltage components in series with the lines. The proposed methodologies are based on the use of line loading security Performance Index (sensitivity factors have been suggested for optimal placement of UPFC. These methods are computationally efficient PI sensitivity factors have been obtained with respect to change in two of the UPFC parameters viz., magnitude and phase angle of the injected voltage in the lines. In (Satakshi Singh, 2012), presented the development of simple and efficient models for suitable location of UPFC, with static point of view, for congestion management. Two different objectives have been considered and the results are compared. Installation of UPFC requires a two-step approach. First, the proper location of these devices in the network must be ascertained and then, the settings of its control parameters optimized. In a power system transmission network, there are some corridors which are lightly loaded whereas some of the corridors are critically loaded and thus power system is operating near to critical state. FACTS plays (S. N. Singh) such as UPFC a vital role in improving the power system performance, both the static and dynamic, and enhanced the system loading capability by rerouting the power flow in the network. Due to excessive cost, these devices must be located optimally.

9) *Others*

The UPFC is a solid state controller which can be used to control active and reactive power flows in a transmission line. In (K.R Padiyar, 1998), has been proposed a control strategy for UPFC in which we control real power flow through the line, while regulating magnitudes of the voltages at its two ports. UPFC (T. Nireekshana, 2010) is used to control the power flow in the transmission systems by controlling the impedance, voltage magnitude and phase angle. This controller offers advantages in terms of static and dynamic operation of the power system. It also brings in new challenges in

power electronics and power system design. The basic structure of the UPFC consists of two VSI; where one converter is connected in parallel to the transmission line while the other is in series with the transmission line.

2) GUPFC

The following performance parameters of systems as follows:

1) Voltage

Electric PQ broadly refers to maintaining a near sinusoidal bus voltage at rated magnitude and frequency. Due to the advancement and proliferation of information technology and the widespread use of power electronic devices in recent years, utilities' customers in various industrial fields are suffering economic losses from short interruptions and voltage flickers (VF). The FACTS devices like SVC's, STATCOM, UPFC and DVR have been able to solve the VF problems by rapidly controlling the RP. In the case of two different sensitive loads in an industrial park fed from two different feeders with different voltage levels, protection from VF can be done by two DVRs having common dc link called IDVR. But in case when the lines are connected with same grid substation and feeding two different sensitive loads in an industrial park, VF in one line affects the VP of other lines. Under the above circumstances, VP cannot be mitigated by IDVR due to insufficient energy storage in dc-link. In (Sujin P. Ra, 2012) - (T. Ruban Deva Prakash, 2007), has been proposed a VF compensator based on GUPFC, which comprises of three VSC modules sharing a common dc link. Two VSC modules connected in series with the lines, compensate VF and a third shunt converter module maintains bus voltage and replenishes the common dc-link energy storage. The control strategy for power flow control of shunt converter and VF compensation control of series converters are derived.

2) *APTC*

Incorporating of GUPFC by the injection power flow GUPFC model and PV/PQ/PQ GUPFC model is the subjected in (M. Z. EL-Sadek).

3) *Others*

A GUPQC by using three single-phase three-level VSCs connected back-to-back through a common dc link is proposed in ref.(Bahr Eldin, 2012) as a new custom power device for a three-feeder distribution system. One of the converters is connected in shunt with one feeder for mitigation of current harmonics and RP compensation, while the other two VSCs are connected in series with the other two feeders to maintain the load voltage sinusoidal and at constant level. The GUPFC (Rakhmad Syafutra Lubis, 2012) is a VSC based FACTS for shunt and series compensation among the multiline transmission systems of a substation is presented.

Shunt Connected-FACTS Controllers

1) STATCOM

The following performance parameters of systems as follows:

1) RP

RP compensation is an important issue in the control of electric PS. RP from the source increases the transmission losses and reduces the power transmission capability of the transmission lines. Moreover, RP should not be transmitted through the transmission line to a longer distance. Hence FACTS devices such as STATCOM, UPFC, and SVC are used to alleviate these problems. In (S. Arockia Edwin Xavier, 2012), a VSC based STATCOM is developed with PI and Fuzzy Controller. Reference (A.M. Sharaf,), has been suggested a novel multi-loop dynamic error driven controller based on the decoupled (d-q) voltage and current tracking for modulating the STATCOM used in distribution networks with dispersed renewable wind energy.

In (Naveen Goel, 2010), a STATCOM is used for VS and the compensation of RP. The STATCOM contains an Insulated Gate Bipolar Transistor (IGBT) based VSC for voltage control and RP compensation. The STATCOM is used to control the RP with the VSC in combination with a DC voltage source.

2) TS

Lack of adequate transmission capacity is a major impediment in connecting more of RESs (such as wind, solar) into the transmission grid. In (Rajiv K. Varma) presented a novel control of a grid connected photovoltaic solar farm to improve TS limit and hence improved APTC of the transmission line. In the night, when the solar farm is completely idle, this new control technique

makes the solar farm inverter behave like a STATCOM a FACTS device. The solar farm inverter then provides voltage regulation at the point of common coupling and improves the stability and transfer limits far beyond minimal incremental benefits. In recent years generation of electricity using WP has received considerable attention worldwide. Induction machines are mostly used as generators in WP based generations. Since induction machines have a stability problem as they draw very large reactive currents during fault condition, RP compensation can be provided to improve stability (Siddhartha Panda, 2007). The dynamic behavior of the example distribution system, during an external three-phase fault and under various types of wind speed changes, is investigated. The study is carried out by three-phase, non-linear, dynamic simulation of distribution system component models. In a deregulated utility environment financial and market forces will demand a more optimal and profitable operation of the PS with respect to generation, transmission and distribution. Power electronic equipment such as FACTS (K. Venkateswarlu) opens up new opportunities for controlling power and enhancing the usable capacity in the existing system. A STATCOM based on the VSC is a widely used shunt FACTS device. The rapid development of power electronics technology provides exciting opportunities to develop new PS equipment for better utilization of existing systems. During the last two decades, number of control devices under the term FACTS offers opportunity to enhance controllability, stability and APTC of AC transmission systems. The insertion of SVC in real time system is presented in (P. Selvan, 2011).

3) SSVS

Reference (Adepoju, 2011), presented the mathematical SS modelling of STATCOM, which is the most widely used member of FACTS. STATCOM Power Injection Model (PIM), derived from one voltage source representation, is presented and analyzed in detailed.

4) Flexible Operation and Control

In (N. Magaji), presented a state feedback control approach to the Single Infinite bus Machine incorporating a STATCOM. In (Linju Jose), a new type of single phase STATCOM for low rating used in customer side is proposed. This new STATCOM is constructed by cascading a full-bridge VSIs to the point of common coupling. A so-called sinusoidal pulse width modulation unipolar voltage switching scheme is applied to control the switching devices of each VSI. A new control strategy is adopted for compensating the harmonics and reactive current required by the load.

5) Protection

The STATCOM (R. Kameswara Rao, 2012) based on VSC is used for VR in transmission and distribution systems. The STATCOM can rapidly supply dynamic VARs required during system faults for voltage support. The apparent impedance is influenced by the RP injected or absorbed by the STATCOM, which will result in the under reaching or over reaching of distance relay.

6) Flexible Operation and Control

Application of FACTS controller called STATCOM (G. Elsady, 2010) to improve the performance of power grid with WPs is investigated .The essential feature of the STATCOM is that it has the ability to absorb or inject fastly the RP with power grid.

7) Optimization Techniques

Power flow control, in an existing long transmission line, plays a vital role in PS area. In this the shunt connected STATCOM (Ravi Kumar Hada, 2012) based FACTS device for the control of voltage and the power flow in long distance transmission line. According to nonlinear operation of STATCOM (N. Farokhnia, 2010), nonlinear controller has a better performance in comparison with linear controller. Regulating the DC capacitor voltage in STATCOM is a common task and can improve the system dynamic. The introduction of FACTS (R. F> Kerendia, 2012) in a power system is to improve the stability, reduce the losses, and also improve the loadability of the network system.

8) Others

In (R. F. Kerendia, 2012), the advantage of STATCOM to compare with SVC are presented. In (John J. Paserba, 2000), a deregulated utility environment, financial and market forces will demand a more optimal and profitable operation of the power system with respect to generation, transmission, and distribution. Power electronic based equipment, such as FACTS, HVDC, and

Custom Power technologies constitute some of the most-promising technical advancements to address the new operating challenges being presented today. The STATCOM (Nagesh Prabhu, 2008) is a shunt connected VSC based FACTS controller using self-commutating devices like GTOs employed for RP control. The principle of operation is similar to that of a synchronous condenser. A typical application of a STATCOM is for VR at the midpoint of a long transmission line for the enhancement of APTC and/or RP control at the load centre.

2) D-STATCOM

The following performance parameters of systems as follows:

1) VP

PQ (Hariyani Mehul, 2011)-(Saeed Mohammadi, 2012) is a major issue in the distribution system (DS). There will be problem occurs regarding RP transfer in distribution system due to large power angle even with substantial voltage magnitude gradient. Here a D-STATCOM is used as a FACT device which can compensate RP. D-STATCOM is three phase VSC used to compensate voltage and make the system stable by absorbing and generating RP. D-STATCOM (Dipesh. M .Patel, 2011) is used for compensation of RP and unbalance caused by various loads in DS.

2) TS

Reference (Ashwin Kumar Sahoo, 2009), has been presented an electromagnetic transient model of FC-TCR is developed and applied to the study of transients due to load variations. The work is then extended to custom power equipment, namely D-STATCOM and Dynamic Voltage Restorer (DVR) aimed at enhancing the reliability and quality of power flows in low voltage distribution networks.

Combined -FACTS Controllers

The following performance parameters of systems as follows:

1) UPFC, GUPFC, and IPFC

1) RP

Shunt FACTS devices, when placed at the mid-point of a long transmission line, play an important role in controlling the RP flow to the power network and hence both the system voltage fluctuations and TS. In (N.M. Tabatabaei, 2008), dealed with the location of a shunt FACTS device to improve TS in a long transmission line with predefined direction of AP flow. The validity of the mid-point location of shunt FACTS devices is verified, with different shunt FACTS devices, namely SVC and STATCOM in a long transmission line using the actual line model. Reference (S. K. Nandha Kumar, 2011), has been proposed an application of Evolutionary Programming (EP) to RP Planning problem using SVC, TCSC and UPFC considering voltage stability. The Fast Voltage Stability Index (FVSI) is used to identify the critical lines and buses to install the FACTS controllers.

2) VS

FACTS devices have been used in PSs since the 1970s for the improvement of its dynamic performance. In [138], the various FACTS related to the benefits and applications of FACTS controllers in electric utilities are presented. Increased electric power consumption causes transmission lines to be driven close to or even beyond their transfer capacities resulting in overloaded lines and congestions. FACTS technology encompasses a collection of controllers, which can be applied individually or in coordination with others to control one or more of the interrelated system parameters. In (Pankaj Jindal), described a FACT controller used in electrical power system. An UPFC is FACTS controller used to control of AP and RP and the IPFC is use for series compensation with the unique capability of power management among multiline of a substation. In (Sunil Kumar Singh, 2012), a consequence of the electric utility industry deregulation and liberalization of electricity markets as well as increasing demand of electric power, the amount of power exchanges between producer and consumer are increases. In this process, the existing transmission lines are overloaded and lead to unreliable system. The countries like India with increasing demand of electric power day by day it is difficult to expand the existing transmission system due to difficulties in right of way and cost problem in transmission network expansion. So, we need power flow controllers to increasing transmission capacity and controlling power flows. FACTS controllers are capable of controlling power flows and enhancing the usable capacity of existing transmission lines. In (Payam Farhadi, 2012), VS of PS has been

investigated in the presence of three types of FACTS controllers including SVC, STATCOM and UPFC. VS and VC point and the loading amount are calculated with and without FACTS controllers. Singh, B., *et al.* (Bindeshwar Singh, 2010), has been presented a exhaustive review of various concept of VI, main causes of VI, classification of VS, DS and SSVS analysis techniques, modeling, shortcomings, in PSs environments. It also reviews various current techniques/methods for analysis of VS in PSs through all over world. VI problems (R. Kalaivani, 2011) increasing day by day because of demand increase. It is very important to analyze the PS with respect to VS by FACTS controllers such as STATCOM, UPFC, SVC, and IPFC. In (J. F. Gronquist, 1996), studied the effects of applying controls for FACTS devices derived from energy functions for lossless systems to systems with losses.

3) TS

In (Xianzhang Lei, 1995), presented a global procedure for parameter settings of FACTS controllers. With the help of the optimization mode in the simulation program system, parameters of controllers associated with the FACTS devices and PSSs in the system are globally determined relying only on local measured information which is available at the FACTS devices themselves. By the minimization of the power oscillations, all possible operation constraints such as VP at each node concerned are considered taking into account the whole non-linear system. The FACTS devices are SVC and TCSC. To meet the strict criteria of grid codes for the integrated wind farm with the grid has become a major point of concern for engineers and researchers today. Moreover VS is a key factor for the stable operation of grid connected wind farm during fault ride through and grid disturbances. In (Naimul Hasan, 2012), has been investigated the implementation and comparison of FACTS devices like STATCOM and SVC for the VS issue for DFIG-based WP connected to a grid and load. The study includes the implementation of FACTS devices as a dynamic voltage restorer at the point of common coupling to maintain stable voltage and thereby protecting DFIG-based WP interconnected PS from isolating during and after the disturbances. Due to the deregulation of the electrical market, difficulty in acquiring rights-of-way to build new transmission lines, and steady increase in power demand, maintaining PS stability becomes a difficult and very challenging problem. In large, interconnected PSs, PS damping is often reduced, leading to lightly damped electromechanical modes of oscillations. Implementation of new equipment consisting high power electronics based technologies such as FACTS and proper controller design become essential for improvement of operation and control of PSs. The aim of (Rusejla Sadikovi'C), is to examined the ability of FACTS devices, such as TCSC, UPFC and SVC for power flow control and damping of electromechanical oscillations in a PS. With increased APTC, TS is increasingly important for secure operation. TS evaluation of large scale PSs is an extremely intricate and highly non linear problem. An important function of transient evaluation is to appraise the capability of the PS to withstand serious contingency in time, so that some emergencies or preventive control can be carried out to prevent system breakdown. In practical operations correct assessment (S. V. Ravi Kumar, 2007) of transient stability for given operating states is necessary and valuable for PS operation. SVC is a shunt connected FACTS devices, and plays an important role as a stability aid for dynamic and transient disturbances in PSs. UPFC controller is another FACTS device which can be used to control active and RP flows in a transmission line. Reference (A. M. Sharaf, 1999), presented a novel flexible, self-adjusting variable series capacitor compensation scheme to enhance TS of an interconnected AC system. An application of a normalized *H1* loop-shaping technique for design and simplification of damping controllers in the LMI framework is illustrated in (Rajat Majumder, 2001). The development of the modern PS has led to an increasing complexity in the study of PS, and also presents new challenges to PS stability, and in particular, to the aspects of TS and SSVS. TS control plays a significant role in ensuring the stable operation of PSs in the event of large disturbances and faults, and is thus a significant area of research. In (D. Murali, 2010), has been investigated the improvement of TS of a two-area PS, using UPFC which is an effective FACTS device capable of controlling the AP and RP flows in a transmission line by controlling appropriately its

series and shunt parameters. Reference (Jungsoo Park, 2008), described modeling VSI type FACTS controllers and control methods for PS dynamic stability studies. The considered FACTS controllers are the STATCOM, the SSSC, and the UPFC. Singh, B., *et al.* (Bindeshwar Singh, 2010), presented an exhaustive review of various methods/techniques for incorporation of differential algebraic equations (DAE) model of FACTS controllers in multi-machine PS environments for enhancement of different operating parameters viewpoint such as damping, VS, voltage security, loadability, AP and energy losses, APTC, cost of generation and FACTS controllers, dynamic performance, and others parameters point of view. It also reviews various current techniques/methods for incorporation of FACTS controllers in PSs through all over world. In (Chintu Rza Makkar, 2010), summarized the various robust control techniques for the enhancement of TS of a large PS. FACTS controllers are being used to damp out the power system oscillations. In (Lijun Cai), concerned the optimization and coordination of the conventional FACTS damping controllers in multi-machine PS. Firstly, the parameters of FACTS controller are optimized. Then, a hybrid FL controller for the coordination of FACTS controllers is presented. This coordination method is well suitable to series connected FACTS devices like UPFC, TCSC etc. in damping multi-modal oscillations in multi-machine PSs.

4) SSVS

In (G. Ramana, 2011), presented an exhaustive review of various concept of VI, main causes of VI, classification of VS, dynamic and static VS analysis techniques, modeling, shortcomings, in PSs environments. It also reviews various current techniques/methods for analysis of VS in PSs through all over world. This literature presented a comprehensive review on the research and developments in the PS stability enhancement using FACTS damping controllers. In (Mohammed Osman Hassan, 2009), SS modeling of SVC and TCSC for power flow studies has been represented and discussed in details. Firing angle model for SVC was proposed to control the voltage at which it is connected. In same manner firing angle model for TCSC is used to control AP flow of the line to which TCSC is installed. The proposed models take firing angle as state variable in power flow formulation. In recent years, power demand has increased substantially while the expansion of power generation and transmission has been severely limited due to limited resources and environmental restrictions. As a consequence, some transmission lines are heavily loaded and the PS stability becomes a power transfer-limiting factor. FACTS (M. A. Abido, 2009)-(G. Ramana, 2011) controllers have been mainly used for solving various PS-SS control problems. However, recent studies reveal that FACTS controllers could be employed to enhance PS stability in addition to their main function of power flow control. The literature shows an increasing interest in this subject for the last two decades, where the enhancement of PS stability using FACTS controllers has been extensively investigated. In PS, one most crucial problem is maintaining PS stability. The main reason for occurring stability problem in the system is due to the sudden increase in load power as well as any fault occurs in the system. There are different types of controllers used in the literature to maintain the stability of the system; among them FACTS controller (A. Satheesh, 2012) plays a major role. Among the different types of FACTS controllers, STATCOM, SSSC, UPFC, TCSC etc, are the most commonly used controllers. To maintain the stability of the system, finding the location for fixing the FACTS controller and also the amount of voltage and angle to be injected is more important. By considering the aforesaid drawback, here a hybrid technique is proposed for identifying the location for fixing FACTS controller and the amount of voltage and angle to be injected in the system in order to maintain the system stability. The hybrid technique includes NN and PSO.

5) Flexible Operation and Control

Singh, B., *et al.* (Bindeshwar Singh, 2008), has been presented a review of several literatures in regarding with various interaction problems and various techniques/methods for coordinated control between PSS and FACTS controllers or FACTS to fact controllers in multi machine PS environments and also review of the various techniques/methods for optimal choice and allocation of FACTS controllers in multi machine PS environments. FACTS are an option to mitigate the problem of overloaded lines due to increased

electric power transmission by controlling power flows and voltages. To avoid mutual influences among several devices placed in the same grid, a coordinated control is indispensable. In (G. Glanzmann), a supervisory controller based on OPF with multiple objectives is derived in order to avoid congestion, provide secure transmission and minimize AP losses. The contributions of SVC, TCSC and TCPST in this coordinated control and the achieved improvements compared with the case where no FACTS devices are in operation are demonstrated. In (L J Cai), the simultaneous coordinated tuning of the FACTS-POD controller and the conventional PSS controllers in multi-machine PSs. Using the linearized system model and the parameter-constrained nonlinear optimization algorithm, interactions among FACTS controller and PSS controllers are considered. In (Sang-Gyun Kang, 2010), presented a centralized control algorithm for PS performance in the Korean PS using FACTS devices. The algorithm is applied to the Korean PS throughout the metropolitan area in order to alleviate inherent stability problems, especially concerns with VS. Generally, control strategies are divided into local and centralized control. In (Tariq Masood, 2010), has been investigated the behavior of STATCOM against SVC controller by setting up new control parameters. Essentially, STATCOM, and SVC linear operating ranges of the V-I and V-Q as well as their functional compensation capabilities have been addressed to meet operational requirement with certain degree of sustainability and reliability. Hereby, the other operating parameters likewise TS, response time, capability to exchange AP and Power Losses have also been addressed in STATCOM against SVC control models.

6) Protection

PSs are subjected to a wide range of small or larger disturbances during operating conditions. Small changes in loading conditions occur continually. The PS must adjust to these changing conditions and continue to operate satisfactorily and within the desired bounds of voltage and frequency. The PS should be designed to survive larger types of disturbances, such as faults, loss of a large generator, or line switching. Certain system disturbances may cause loss of synchronism between a generator and the rest of the utility system, or between interconnected PSs of neighboring utilities. If such a loss of synchronism occurs, it is imperative that the generator or system areas operating asynchronously are separated immediately to avoid widespread outages and equipment damage (Demetrios A. Tziouvaras). The presence of series connected FACTS devices like TCSC, TC-PST and UPFC etc. can drastically effect the performance of a distance relay in a two terminal system connected by a double-circuit transmission line. The control characteristics of the series connected FACTS devices, their locations on the transmission line, the fault resistance especially the higher ones make this problem more severe and complicated (P K Dash, 2000). In (Mohamed Zellagui, 2012), has been presented a study on the performances of distance relays setting in 400 kV in Eastern Algerian transmission networks at Sonelgaz Group (Algerian Company of Electricity) compensated by shunt FACTS. The FACTS are used for controlling transmission voltage, power flow, reactive power, and damping of PS oscillations in high power transfer levels. References (Fadhel A Albasri, 2007), presented a comparative study of the performance of distance relays for transmission lines compensated by shunt connected FACTS controllers/ devices. The objective of this study is to evaluate the performance of various distance protection schemes on transmission lines with shunt-FACTS devices applied for midpoint voltage control. The impact of two types of shunt FACTS devices, SVC and STATCOM on the transmission line distance protection schemes is studied for different fault types, fault locations and system conditions. FACTS (Kishor Porate, 2009) devices are installed in the transmission network to divert the power flow, minimize the power losses and to improve the line performance but it has some limitations and drawbacks. Distributed-FACTS is a improved version of FACTS devices which is used to improve the security and reliability of the network in a cost effective manner. In (Mohamed Zellagui, 2012), has been presented a comparative study of the performance of distance relays for transmission line high voltage (HV) 400 kV in Eastern Algerian transmission networks at Group Sonelgaz compensated by two different series FACTS i.e. GTO GCSC and TCSC connected at midpoint of an electrical transmission line. The facts are used for controlling transmission voltage, power flow,

reactive power, and damping of power system oscillations in high power transfer levels.

7) APTC

The necessity to deliver cost effective energy in the power market has become a major concern in this emerging technology era. Therefore, establishing a desired power condition at the given points are best achieved using power controllers such as the well known HVDC and FACTS devices. HVDC is used to transmit large amounts of power over long distances. The factors to be considered are Cost, Technical Performance and Reliability. A FACTS (M. Ramesh, 2011) is a system composed of static equipment used for the AC transmission of electrical energy. It is meant to enhance controllability and increase power transfer capability of the network. It is generally a power electronics-based system. A UPFC is a FACTS device for providing fast-acting RP compensation on high voltage electricity transmission networks. The UPFC is a versatile controller which can be used to control AP and RP flows in a transmission line. Singh, B., *et al*. (Bindeshwar Singh, 2010), has been presented a comprehensive survey of incorporation of FACTS controller such as SVC, TCSC, SSSC, STATCOM, UPFC, and IPFC devices in NRFL for power flow control. FACTS technology opens up new opportunity for operation and control of power system. Out of the various FACTS devices (viz TCSC, TCPST, UPFC etc.), the right choices for the maximization of power flow in power system network demands attention which helps to achieve the active power flow up to their line limits without any constraint violation and with optimal investment on FACTS devices. In (A K Chakraborty, 2011), an algorithm has been developed for right choices of various combination of FACTS in the power network to enhance the power transfer capability of existing lines under normal condition very close to their line limits and has been applied for modified IEEE 14- bus system. Congestion of transmission capability often 1imits the operation of power markets. Because of the substantial costs that such congestion causes and difficulties in improving transfer capacity through transmission expansion, FACTS devices (M ats Larsson, 2005) are increasingly often considered as short-term solutions to congestion problems. This paper shows that such FACTS devices are most often not used to their ful1 potential unless equipped with control systems based on wide-area measurements. In a deregulated utility environment, financial and market forces will demand a more optimal and profitable operation of the power system with respect to generation, transmission, and distribution. Power electronic based equipment, such as FACTS (John J. Paserba, 2000), HVDC, and Custom Power technologies constitute some of the most-promising technical advancements to address the new operating challenges being presented today. In (J. Amratha Manohar, 2011), presents an efficient method for calculation of Transfer Capability adopting Breadth First Search Algorithm. The Breadth First Search Algorithm like Dijkstra's algorithms' is a graphical approach to determine the optimum operating state of the network and thereby calculate the Available Transfer Capability of the Transmission lines and areas. Several methods have been developed for determining Available Transfer Capability. In (Adepoju G. A., 2011), presented the results of power flow analysis of Nigerian power system incorporating FACTS controllers such as STATCOM, HVDC-VSC and UPFC for voltage magnitude control, active and reactive power flow control. In (A. Abu-Siada, 2012), has been investigated different approaches to improve the power transfer capability (PTC) of transmission lines. Study was performed on the Eastern Gold Fields (EGF) area of the Western Power network in Western Australia where power transfer to this area is currently enhanced using four saturable reactor-SVCs installed in this region. These SR SVCs have reached to the end of operational life and they are scheduled for replacement by different dynamic reactive power devices such as STATCOMs or SVCs TSVCs. In (Claudio A. Canizares, 2000), presented transient stability and power models of TCR and VSI based FACTS Controllers. Models of the SVC, the TCSC, the STATCOM, the SSSC, and the UPFC appropriate for voltage and angle stability studies are discussed in detail. With the restructuring of electrical power industry there has been great interest computation of (ATC) of power systems. In (Xiao-Ping Zhang, 2002), the mathematical models of FACTS controllers such as STATCOM,SSSC, UPFC and the latest IPFC and GUPFC are established and a nonlinear optimization framework with comprehensive modeling of these facts controllers is proposed.

8) *Optimal Location of FACTS controllers*

Singh, B., *et al.* (Bindeshwar Singh, 2010), has been presented an exhaustive review of various methods/techniques for coordinated control between FACTS controllers in multi-machine power systems. It also reviews various techniques/ methods for optimal choice and allocation of FACTS controllers. To enhance power system transient stability, shunt FACTS (Ahsanul Alam) devices can be controlled in discontinuous mode or in a combination of discontinuous and continuous mode. In continuous mode proportional controller is usually used. In (Nikhlesh Kumar, 2003), a new method called the extended voltage phasors approach (EVPA) is proposed for placement of FACTS controllers in power systems. While the voltage phasors approach (VPA) identifies only the critical paths from the voltage stability viewpoint, the proposed method additionally locates the critical buses/line segments. The results of EVPA are compared with the well-established line flow index (LFI) method for nine-bus, 39-bus, and 68-bus systems. It is shown that the EVPA provides accurate indication for the placement of FACTS controllers in power systems. Shunt FACTS device such as SVC and STATCOM (M Kowsalya, 2009), when placed at the midpoint of a long transmission line, play an important role in controlling the reactive power flow to the power network and hence both the system voltage fluctuations and transient stability. The introduction of FACTS (Prakash G. Burade, 2005-2010) in a power system improves the stability, reduces the losses, reduces the cost of generation and also improves the loadability of the system. Reference (K Vijayakumar, 2005-2007), presented a novel method for optimal location of FACTS controllers in a multi machine power system using GA. Using the proposed method, the location of FACTS controller, their type and rated values are optimized simultaneously. Among the various FACTS controllers, TCSC and UPFC are considered. The proposed algorithm is an effective method for finding the optimal choice and location of FACTS controller and also in minimizing the overall system cost, which comprises of generation cost and investment cost of FACTS controller using GA and conventional NRFL method. The FACTS in a power system plays a vital role in improving the power system performance, both the static and dynamic, where improving the stability, reducing the losses and the cost of generation, also enhancing the system loading capability with rerouting the power flow in the network. In order to reach the above goals, these devices must be located optimally. In the proposed work, the sensitivity of system loading factor, corresponding to the real and reactive power balance equations with respect to the control parameters of FACTS (Rakhmad Syfutra Rubis), technique plus N-1 contingency criterion with some considerations that fitting with formation of the network are used to consider the location and type of the devices. Furthermore the optimal location and parameter are tested and found with the nonlinear predictor-corrector primal-dual interior-point OPF algorithm. Shunt FACTS devices are used for controlling transmission voltage, power flow, reducing reactive losses, and damping of power system oscillations for high power transfer levels. In (P R Sharma, 2007), the optimal location of a shunt FACT device is investigated for an actual line model of a transmission line having series compensation at the center. Effect of change in degree of series compensation on the optimal location of the shunt FACTS device to get the highest possible benefit is studied. It is found that the optimal location of the shunt FACTS device varies with the change in the level of series compensation to get the maximum benefit in terms of APTC and stability of the system. Singh, B., *et al.* (Bindeshwar Singh, 2011), presented a state-of-the-art on enhancement of different performance parameters of power systems by optimally placed Distributed Generation (DG) & FACTS controllers in power Systems. In (M Santiago- Luna, 2006), an algorithm for optimally locating FACTS controllers in a power system is presented. The proposed methodology is based on EA known as Evolution strategies (ES). In (Naresh Acharya), presented various facts related to the landmark development: practical installations, benefits and application of FACTS controllers in the electric utilities. The history of development of these devices is presented along with the information regarding the first utility installation/demonstration of FACTS devices.

9) *Others*

Elliptic Curve Cryptography (ECC) is coming forth as an attractive public key cryptosystem for mobile/wireless environments compared to conventional cryptosystems like RSA and DSA.

ECC provides better security with smaller key sizes, which results in faster computations, lower power consumption, as well as memory and bandwidth savings. However, the true impact of any public-key cryptosystem can only be evaluated in the perspective of a security protocol. The digital signature is the requisite way to ensure the security of web services and has great implication in practical applications. By using a digital signature algorithm we can provide authenticity and validation to the electronic document. ECDSA and ECDH use the concept of ECC (Shipra Shukla, 2012). Modern power systems are continuously being expanded and upgraded to cater the need of ever growing power demand. But, in recent years, energy planners have faced financial and environmental difficulties in expanding the power generation and transmission systems. These difficulties included limited available energy resources, time and capital required and also the land use restrictions etc. These situations have forced planning engineers to look for new techniques for improving the performance of existing power system. This is a review paper to analyze the current trends in FACTS and D-FACTS to improve the performance of power system performance. It contains work which has been carried out by various researchers in the field of FACTS and D-FACTS (V. Kakkar, 2010). In (John J. Paserba),provided a summary of one of the three planned presentations on the topic of "FACTS Fundamentals," for a session sponsored by the DC and FACTS Education Working Group, under the DC and FACTS Subcommittee of the T&D Committee. This paper is on Part I of the session and focuses on a summary of the issues and benefits of applying FACTS controllers to AC power systems. The overall process for system studies and analysis associated with FACTS installation projects and the need for FACTS controller models is also discussed. Singh, B., *et al.* (John J. Paserba), has been presented a critical review on different application of Phasor Measurement Units (PMUs) in electric power system networks incorporated with FACTS controllers for advanced power system monitoring, protection, and control. Also this paper presents the current status of the research and developments in the field of the applications of PMUs in electric power system networks incorporated with FACTS controllers. The performance of power systems decreases with the size, the loading and the complexity of the networks. This is related to problems with load flow, power oscillations and voltage quality. Such problems are even deepened by the changing situations resulting from deregulation of the electrical power markets, where contractual power flows do no more follow the initial design criteria of the existing network configuration. Additional problems can arise in case of large system interconnections, especially when the connecting AC links are weak. FACTS devices, however, provide the necessary features to avoid technical problems in the power systems and they increase the transmission efficiency (D. Povh, 2003). In (Bindeshwar Singh, 2010), presented an exhaustive review of various methods/techniques for coordinated control between FACTS controllers in multi-machine power systems. Power flow models of Convertible Static Compensators for large-scale power systems are investigated. Two families of multi-configuration and multi-functional FACTS controllers, including IPFC and GUPFC, are considered in details. Mathematical models of the IPFC and GUPFC based on d-q axis reference frame decomposition have been derived. A unified procedure to incorporate IPFC and GUPFC (Sheng-Huei Lee) models into the conventional NRFL solver is developed. The development of the modern power system has led to an increasing complexity in the study of power systems, and also presents new challenges to power system stability, and in particular, to the aspects of transient stability and small-signal stability. Transient stability control plays a significant role in ensuring the stable operation of power systems in the event of large disturbances and faults, and is thus a significant area of research. In (D Murali, 2010), investigated the improvement of transient stability of a two-area power system, using UPFC which is an effective FACTS device capable of controlling the active and reactive power flows in a transmission line by controlling appropriately its series and shunt parameters. Electricity market activities and a growing demand for electricity have led to heavily stressed power systems. This requires operation of the networks closer to their stability limits. Cost effective solutions are preferred over network extensions. The FACTS, a new technology based on power electronics, offers an opportunity to enhance controllability, stability, and power transfer

capability of ac transmission systems (Pavlos S. Georgilakis, 2011).

Congestion of cross-border transmission capabilities often limits the operation of power markets. Because of the substantial costs that such congestion cause, and difficulties in improving transfer capacity through transmission expansion, FACTS (Mats Larsson, 2004) devices are increasingly often considered as short-term solutions to congestion problems. In (Mats Larsson, 2004), showed that such FACTS devices are most often not used to their full potential unless equipped with control systems based on wide-area measurements. The presented novel control strategies that coordinate and optimize the setpoints of several FACTS devices to achieve optimum benefit from FACTS installations in terms of steady-state loadability increase. Recently, GA and Differential Evolution (DE) algorithm technique have attracted considerable attention among various modern heuristic optimization techniques. Since the two approaches are supposed to find a solution to a given objective function but employ different strategies and computational effort, it is appropriate to compare their performance. In (A K Balirsingh, 2011), presented the application and performance comparison of DE and Gam optimization techniques, for FACTS-based controller design.

Power electronics based controllers, built on solid state silicon switches, offer control of the power grid with the speed and precision of a microprocessor, but at a power level of 500 million times higher. They allow utilities to direct power along specific corridors, aligning the physical flow of power with commercial transactions. In a multi terminal system, HVDC (P V Chopade, 2007) can also be connected at several points with the surrounding three-phase network. The fast development of power electronics based on new and powerful semiconductor devices has led to innovative technologies, such as HVDC and FACTS, which can be applied in transmission and distribution systems. The technical and economical benefits of these technologies represent an alternative to the application in ac systems. Deregulation in the power industry and opening of the market for delivery of cheaper energy to the customers is creating additional requirements for the operation of power systems. HVDC and FACTS offer major advantages in meeting these requirements (Dusan Povh, 2000). In (Ajit Kumar Verma), proposed an optimization model to use in composite power system reliability evaluation method incorporating the impact of FACTS devices. The conventional dc flow-based linear programming model used in composite system reliability evaluation method is converted into a non-linear optimization model to include the impact of FACTS devices on reliability of power system. Power electronic loads introduce harmonic currents into the utility power system. This paper presents harmonic reduction techniques, which satisfy the current harmonic limits. The techniques which are considered here, are active filter, hybrid filter and zig-zag transformer rectifier as FACTS controllers. According to rectifying or inverting operation of HVDC converters, reactive power is absorbed from the bus in which the converter is connected. In either case of operation reactive power compensation in AC side of converters is quite necessary. In addition to reactive power compensation, due to nonlinear behavior of power electronics converters (Sardar Ali, 2009). The electric power supply industry, with more than 100 years history, has evolved into one of the largest industries. Secure and reliable operation of the electric power system is fundamental to economy, social security and quality of modern life. The complicated power grid is now facing severe challenges to meet the high level secure and reliable operation requirements, which include lack of transmission capability, restraints by a competitive market environment, and power infrastructure vulnerability. New technologies will play a major role in helping today's electric power industry to meet the above challenges. In (Li Zhang), has been focused on some key technologies among them, including the emerging technologies of energy storage, controlled power electronics and wide area measurement technologies. Those technologies offer an opportunity to develop the appropriate objectives for power system control. In bulk power transmission systems, the use of power electronics based devices with energy storage system integrated into them, such as FACTS/ESS, can provide valuable added benefits to improve stability, PQ, and reliability of power systems. There is a lack of scientific mechanisms to guide their technical decisions making process, even though many electric utilities in the U.S. and all over the world are beginning to implement

FACTS/ESS for many different applications. The study has been provided several guidelines for the implementation of FACTS/ESS in bulk power systems. The interest of this study lies in a wide range of FACTS/ESS technology applications in bulk power system to solve some special problems that were not solved well without the application of FACTS/ESS. The special problems we select to solve by using FACTS/ESS technology in this study include power quality problem solution by active power compensation; electrical arc furnace (EAF) induced problems solution, inter-area mode low frequency oscillation iii suppression, coordination of under frequency load shedding (UFLS) and under frequency governor control (UFGC), wide area voltage control. From this study, the author of this dissertation reveals the unique role that FACTS/ESS technology can play in the bulk power system stability control and power quality enhancement in power system. This study presented a comprehensive review of various methods/techniques for incorporation of differential algebraic equations (DAE) model of FACTS controllers and different type of loads such as a static, dynamic, and composite load model in large-scale emerging power systems for enhancement of loadability of power system networks (bindeshwar Singh, 2010). In (Lamia Kartobi), presented a simple method to simultaneously tune FACTS in multi-machine power systems. The proposed approach employs GA and PSO. Extended interconnected systems experience stability problems and inter-area oscillations, which can lead to system interruptions. Furthermore, long distance ac transmission requires RP compensation, introducing stability constrains that limit transmitted power. These conditions can be improved by the use of FACTS controllers. These improvements can be predicted by the proper simulation of FACTS controllers, which include all controls and a detailed representation of the system (Dussan Povh, 2000). In (John J. Paserba), provided a summary of one of the three planned presentations on the topic of “FACTS Fundamentals,” for a session sponsored by the DC and FACTS Education Working Group, under the DC and FACTS Subcommittee of the T&D Committee. This paper is on Part I of the session and focuses on a summary of the issues and benefits of applying FACTS controllers to AC power systems. The overall process for system studies and analysis associated with FACTS installation projects and the need for FACTS controller models is also discussed. In (Laslzlo Gyugi, 2000), presented the switching-converter-based approach to FACTS from an application viewpoint. It is shown that this approach, apart from providing superior performance character-ristics when applied for shunt and series reactive compensation, also offers modular expandability and functional convertibility for comprehensive real and reactive power flow, as well as voltage control, for a single transmission line or for a multi-line network, making system-wide optimization and maximum asset utilization possible. In (Bindeshwar Singh, 2009-2011)-(Bindeshwar Singh, 2010), presented a comprehensive review on enhancement of power system stability such as rotor angle stability, frequency stability, and voltage stability by using different FACTS controllers such as TCSC, SVC, SSSC, STATCOM, UPFC, IPFC in an integrated power system networks. Also this paper presents the current status of the research and developments in the field of the power system stability such as rotor angle stability, frequency stability, and voltage stability enhancement by using different FACTS controllers in an integrated power system networks. In (Nanda Kumar Easwaramoorhty, 2012), presented a new approach for optimal location of FACTS controllers in a multi machine PS using MATLAB coding. Using the proposed method, the location of FACTS controller, their type and rated values are optimized simultaneously. Among the various FACTS controllers, TCSC and UPFC are considered. In (Bindeshwar Singh, 2011), presented a critical review on different application of PMUs in electric PS networks incorporated with FACTS controllers for advanced PS monitoring, protection, and control. In recent years, power demand has increased substantially while the expansion of power generation and transmission has been severely limited due to limited resources and environmental restrictions. As a consequence, some transmission lines are heavily loaded and the system stability becomes a power transfer-limiting factor. FACTS controllers have been mainly used for solving various PS-SS control problems. However, recent studies reveal that FACTS (M A Abido, 2009) controllers could be employed to enhance PS stability in addition to their main function of power flow control. In (Sidhartha Panda, 2007), presented a systematic procedure for modelling and simulation of a PS installed with a

PSS and a FACTS-based controller. The strong resonance phenomenon noticed in PSs with mode coupling is characterized by coincidence both of eigenvalues and eigenvectors. It is a precursor to the oscillatory instability and hence it is necessary to consider the effect of strong resonance on the coupled modes while designing a damping controller for a system. The work presented in (H V Sai Kumar, 2008) aims at tuning supplementary modulation controllers for two FACTS controllers (each considered separately) to enhance the stability of a 2-machine system, which experiences a near-resonance phenomenon due to modal interaction when the power dispatch of the generators is varied (H V Sai Kumar, 2008). FACTS (A K Chakraborty, 2011) technology opens up new opportunity for operation and control of PS. Out of the various FACTS devices (viz-TCSC, TCPST, UPFC etc.), the right choices for the maximization of power flow in PS network demands attention which helps to achieve the AP flow up to their line limits without any constraint violation and with optimal investment on FACTS devices. In (Naresh Acharya, 2007), proposed two new methodologies for the placement of series FACTS devices in deregulated electricity market to reduce congestion. SVC (Irinjila Kirti Karan, 2011) involved the management of RP for the improvement of electric PS performance. Adequate RP control solves PQ problems like flat VP maintenance at all power transmission levels, and improvement of power factor, transmission efficiency and PS stability. Series and Shunt VAR compensation techniques are used to modify the natural electrical characteristics of electric PS. Series compensation modifies the reactance parameter of the transmission or distribution system, while shunt compensation changes the equivalent load impedance. In both cases, the line RP can be effectively controlled thereby improving the performance of the overall electric PS. In (Bindeshwar Singh, 2011), presented a comprehensive survey on the mitigation of PQ problems such as low power factor, shortage of RP, poor voltage, voltage and current harmonics due to sudden change in field excitation of synchronous alternator, sudden increased in load, sudden fault occur in the system are solved by FACTS controllers such as STATCOM, DSTATCOM, and D2STATCOM. In emerging electric PSs, increased transactions often lead to the situations where the system no longer remains in secure operating region. The FACTS controllers can play an important role in the PS security enhancement. However, due to high capital investment, it is necessary to locate these controllers optimally in the PS. FACTS devices can regulate the AP and RP control as well as adaptive to voltage-magnitude control simultaneously because of their flexibility and fast control characteristics. Placement of these devices in suitable location can lead to control in line flow and maintain bus voltages in desired level and so improve VP margins (Ch. Rambabu, 2011).

Third Generation of FACTS Controllers

The following FACTS controllers are coming in third generation as follows:

1) FMRL

The following performance parameters of systems as follows:

1) TS

The parameters of PS slowly change with time due to environmental effects or may change rapidly due to faults. It is preferable that the control technique in this system possesses robustness for various fault conditions and disturbances. The used FACTS in [226] such as advanced super-conducting magnetic energy storage (ASMES). Many control techniques that use ASMES to improve PS stability have been proposed.

2) PS Stability

Various control techniques using ASMES (Abdellatif Naceri, 2008) aimed at improving PS stability have been proposed. As FL controller has proved its value in some applications, the number of investigations employing FL controller with ASMES has been greatly increased over recent period.

2) HPFC

The following performance parameters of systems as follows:

1) TS

Recently, a novel HPFC topology for FACTS has been proposed (Lini Mathew, 2012).

2) RP

In (Rakesh Babu, 2011), reported the investigation

on the implementation of control technique based on Adaptive Back stepping Controller in a PS incorporating the HPFC (Rakesh Babu, 2011). The objective is to archive effective control of the AP and RP flow in the line with minimum or zero dynamic interactions between them.

3) Others

Two novel power flow controller topologies are proposed for FACTS controllers such as UPFC. The first one consists of a shunt connected source of RP, and two series connected VSC one on each side of the shunt device. The second topology is a dual of the first; it is based on two shunt connected VSCs around a series connected reactive element. In both cases the converters can exchange AP through a common DC circuit. Both topologies make combined use of passive components and converters and can therefore be regarded as hybrid. Employing hybrid topologies enables use of converters to enhance the functionality of existing equipment in a PS (Jovan Z. Bebic, 2006).

Combined FACTS Controllers

UPFC, GUPFC, IPFC, and HPFC

In (Bindeshwar Singh, 2012), presented a state-of-the-art on enhancement of different performance parameters of PSs such as VP, damping of oscillations, load ability, reduce the AP and RP losses, SSR problems, TS, and dynamic performance, by optimally placed of FACTS controllers such as TCSC, SVC, STATCOM, SSSC, UPFC, IPFC, HPFC in WP Systems. In (Bindeshwar Singh, 2011), presented the introduction of various FACTS controllers such as SVC, TCSC, TCPAR or TCPAT, SSSC, STATCOM, UPFC, IPFC, GUPFC, HPFC for operation, control, planning & protection from different performance point of view such as increased the loadability, improve the VP, minimize the AP losses, increased the APTC, enhance the TS and SSVS, and flexible operations of PSs.

Summary of the Paper

The following tables give summary of the paper as follows:

Conclusions

In this paper, an attempt has been made to review, various literatures for the application of FACTS controllers such series, shunt, series-shunt, and series-series connected FACTS controllers are in power system environments for enhancement of performance parameters of systems as RP support, minimize the AP losses, improvement in VP of systems, improvement in damping ratio of PSs, flexible operation and control of systems, etc. This review article also presents the current status on application of FACTS controllers in PSs for enhancement of performance parameters of systems.

TABLE 4 GENERATION OF FACTS CONTROLLERS POINT OF VIEW

Generations of FACTS Controllers	Total No. of Literatures Reviews out of 232 Literatures	% of Literatures Reviews out of 232 Literatures
I Generation	58	25 %
II Generation	167	71.98 %
III Generation	7	3.01%

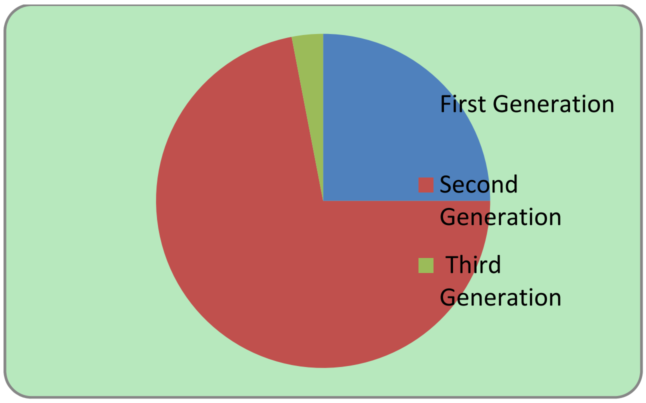


FIGURE 1 GENERATION OF FACTS CONTROLLERS POINT OF VIEW WITH CHART

ACKNOWLEDGMENT

The authors would like to thanks Prof. (Dr.) S. N. Singh, IIT, Kanpur, U.P., India, for discussions regarding with applications of FACTS Controllers in PSs for enhancement of performance parameters of systems.

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